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Prospects for the Application of BIM in the Building Operation and Maintenance Phase

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Abstract. This study takes a literature review approach on the current status of Building Information Modeling (BIM) applications in the building operation and maintenance (O&M) phase. Current studies show that the application of BIM in this field is still struggling with several problems including information fragmentation, unfixed operation patterns, and over-dependence on human decision-making. To address the above problems, this paper puts forward three development directions of BIM by integrating with digital twin technology, machine learning algorithms, and others. First, a digital twin-based integrated platform is put forward to solve the problem of information fragmentation. Secondly, the integration with artificial intelligence (AI) is discussed to change the decision-making method from passive to active. Finally, the contribution of BIM is extended from the use phase to the resource circulation phase in the circular economy. This paper summarizes the three development directions put forward in this paper, as well as the challenges that may be faced in the future development of BIM in the O&M phase.

Keywords: BIM, Building operation and maintenance, Integration of AI and architecture.

1. Introduction

Building Information Modeling (BIM) is, at the moment, one of the most widely used theories of managing building data. It is a method, which enables specialists to address the information of the entire life cycle of a structure, which begins with the creation of its design, to its building, delivery, and utilization of the building. BIM achieves this by integrating data of different disciplines into a three-dimensional model, which enables effective communication and coordination of all the stakeholders and the inclusion of structural performance, seismic resistance, daylighting and material data [1].

The operation and maintenance (O&M) phase consumes the largest resources and the longest amount of time (comprising approximately 80 percent of the total life-cycle cost) and is over 15 times longer than the other two phases put together [2,3]. Nevertheless, the available statistics give the BIM adoption rates of 79.7% during the design stage and 59.5% during the construction stage and the BIM adoption rates during the O&M stage are only 12.2% [4]. This difference implies that BIM is much more advanced in terms of its applications in design and construction whereas the application of BIM to building O&M has only been at the first stage.

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At present, there are some limitations to the application of BIM in building O&M. First, the integration problems encountered by technical staff, and the interoperability between systems such as CMMS, CAFM and BAS are not good enough [5]. Secondly, most of the data are still presented in the form of static data, such as charts, drawings or static 3D models [6]. Static data cannot be updated in real time, which easily causes the information model to be detached from the site. In addition, it can only provide help for existing management and requires a large number of corrective measures, and provides little help for future prediction. Thirdly, due to the information support of BIM in the O&M phase still not enough, and the coordination problems have not been well solved, so the operation and maintenance of the building still relies on a large amount of traditional experience of the facility manager, which is prone to decision errors and high operation and maintenance costs [7]. Therefore, the BIM model established in the planning and design stage of the building and the construction stage with a large amount of manpower, material resources and time is not fully utilized in the process of building operation and maintenance, resulting in a waste of previous efforts.

Against this backdrop, the present literature review study investigates the development prospects of BIM in the building O&M phase. Differentiating itself from existing reviews that only list BIM-related O&M technologies, the present paper introduces a systematic development framework consisting of three sequential levels: information integration, intelligent options, and life-cycle prolongation.

2. Development needs of BIM in building operation and maintenance

With rapid advances in technology, data and systems integration have progressed to the point that automatic operation management can now be seen as a choice for building operations, with rules-based decision making, automation, and human presence requiring a well-calibrated balance [7]. A balance should be struck between all three, with the first two requiring a human presence where machinery cannot replicate human skills [6].

Currently, the applications of BIM technology in O&M are mainly in the areas of spatial and asset management, energy consumption monitoring and operational optimization, and model assistance for building renovation and retrofitting [8]. Although the application scenarios are relatively clear, the current status is still mainly characterized by scattered applications, single application scenarios, and merely supporting human management but without independent and intelligent management capabilities. There is still a long way to go to the large-scale and standardized deep integration applications of BIM technology in building O&M.

Utilization of BIM combined with other technologies like digital twins, automated control, and machine learning yields a huge promise to decrease the cost of labor and errors in decision-making while increasing the level of digitalization, automation, and intelligence in O&M management [9,10].. Besides, the dismantled buildings' remaining value can be added to the list of reusability assets, and their BIM models should be researched to back up the expansion of BIM over the entire building cycle. This study proposes three development directions for further consideration from the current situation of BIM integration in building O&M.

2.1. Establishing a unified platform based on digital twin technology

The limitations that BIM is suffering from in O&M today are not because of the BIM itself but the fact that information is fragmented across various domains. BIM, CMMS, ERP, and IoT applications

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each have their sets of information that need to be integrated [5,6]. BIM should be transformed into a dynamic digital twin.

In case there's a need for interfacing between different software systems, the number of interfaces gets exponentially bigger, and this way of integration is quite complex, inefficient, and error prone. Instead, all the required software systems and solutions like BIM, CMMS, ERP, IoT, etc., can connect to a central data intermediary via APIs, with fewer interfaces between different software systems.

The platform may be classified into three layers, i.e., Data Layer, Service Layer and Application Layer. Data Layer primarily concentrated on ingathering data from multiple software platforms, labeling it and mapping the labels together for query and retrieval. Service Layer is an administrator of the Data and Application Layer. It works towards converting the data into a common format and delivers services like query, availing alarms and analysis. Application Layer is beneficial for the technical community, Managers as well as Policy Makers with the following models: Dynamic 3D models, equipment monitoring portals, energy analysis, etc.

This platform can also be connected to IFC, dealing with software-agnostic model exchange; Brick Schema, focusing on O&M semantics; and COBie, allowing structured presentation of O& M delivery information. BIM is the data framework, while the captured real-time building data, such as temperature, vibration, and energy consumption monitored by IoT systems are described in the BIM model to build a true digital twin, so the technician doesn't have to look for multiple software platforms to extract the desired data but can integrate information directly from the platform.

Besides, BIM could be applied for precisely locating the defective hardware after which CMMS can automatically create work order. In such a way, the total procedure could be simplified, coordination approach among software applications improved, and time and money minimized.

2.2. Enhancing decision accuracy through the integration of BIM, machine learning, and automated control

Currently, AI use in O&M in BIM-based applications has progressed beyond theoretical conceptions and into localized implementations, but the scope is limited to predictive maintenance, energy efficiency, and digital twinning [7]. Real-world applications are mostly centered around functional demonstration and project-based implementation, but with little focus on the differences between types of AI and applicability in specific contexts.

Indeed, various AI technologies possess different functionalities for building O&M. For instance, machine learning is capable of processing and summarizing historical fault information; with natural language processing one can identify keywords and summarize fault information in work/purchase orders and repair records; computer vision can extract defect information such as stains, scratches and cuts by processing images, videos, etc. It can be seen from these characteristics that AI tools have rich development space in terms of building O&M.

Nevertheless, the primary problem is not in the childishness of the AI algorithms as such, but in the unavailability of complex and permanent information input, which would be necessary for the training and making reliable recommendations for technical specialists. Consequently, generative AI is limited to producing localized intelligence in a specific context and cannot yet provide dynamic updates across systems or cover the entire building life cycle.

In order to resolve the problem, AI should first be linked to the intermediate data platform mentioned above, which can provide the requisite material and experience solid model for training the AI with a continuous, all-encompassing, and dynamic digital model on the cloud system. Second, AI interventions should be foreseen at certain subsystems that will eventually be

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incorporated within a larger system. Since the complexity of buildings and the information nature of different subsystems vary widely, deploying a single AI to control a building remains potentially confusing, and it has a high probability of error.

A better approach is to build different AI machine models focused on different building subsystems, as those show different features, which are unique and specific to the subsystems and their data, then incorporate those into a broader BIM-based model. The process can involve the following actions. First, the building subsystems (like drainage, lighting, elevator, etc.) are identified. Second, the relevant data of each subsystem are identified for subsequent modeling separately, which is beneficial as it prevents the model from being fed with a huge mass of building data. Third, the results of the modeling of those subsystems are reflected into the BIM model and attached to particular building elements and equipment. Fourth, the results of the subsystems modeling are summarized on the platform for further analytics and management.

When multiple AI archetypes collaborate, they can generate recommendations to decision-makers with fleshed out support of differentiated analytics in different scenarios and thus enhance not only the accuracy of the decision-making but also the interpretability of AI. In contrast to training one AI archetype to master the whole rich information about the building, modularized training decreases the burden, duration and cost of the development of AI relatively.

2.3. Reuse of building model information

When an existing building has reached the end of its life and is facing demolition or reconstruction, information such as material characteristics, spatial distribution of building components and equipment contained in its BIM model should be retained. In this way, the building can be converted from a 'waste object' into a distinguishable, disassemble and recyclable resource, embodying its role as an 'urban mine.' At this point, however, there is a lack of discussion and research in the field of information reuse at the end of the life cycle of buildings, and information models produced after the demolition show significant shortcomings in management, despite the high potential of the sector.

First, the information available in the BIM data includes the position of internal elements, the connections between the elements, the material type and the position of the different equipment. The information may be utilised to assist the demolition contractor in determining the possible hazards within various sections of a building and enhance the process of demolition, such as transportation, sorting, and recycling. The operations involving the demolition process can also be guided by the use of schema data that will reduce costs incurred due to inappropriate demolition practices, inappropriate dismantling of the buildings, or contamination of waste.

Secondly, in the case of a building undergoing deconstruction, the BIM system can store not just the data on space and structure, but also on material information and basic data concerning the material in the BIM system. This may be applicable to study the properties and metamorphosis of the materials over the life of the building that may be applicable in the manufacture of new substances, reuse of materials, and recycling. Moreover, the data of the structure kept in BIM can be utilized to understand whether the structure data of the building remains sufficient to be reused, and, therefore, improve the reusability of the building components and materials and lead to the economic circulation.

Finally, the residual BIM model can also be used for further life cycle assessment (LCA), calculation of carbon emissions, and analyses or observations of policies and science. Through the assessment of the whole life cycle of an LCA BIM model, including cost, process of construction, and the environmental performance of the entire cycle, it is possible to better explore the application of BIM models to the whole life cycle of a building and stimulate new demand for the sustainable

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development of the construction industry. In this sense, the application of BIM models at the end-of-life cycle of a building should be more delimited than just the preservation of the original building's BIM model, but rather aimed at the assignment of an information state before, during, and after the demolition process, in order to ensure the potential of the BIM model for further resource recovery and analyses.

3. Conclusion

Overall, the utilization of building operation and maintenance using BIM technologies is less advanced than the use of BIM in building design and construction, but nevertheless, it has great potential for future development. The secret to developing this area of BIM is not only improving the BIM technologies themselves, but also developing skills and competencies needed to respond to the needs of building O&M.

To address the problems facing the field today, such as inconvenience for technical professionals to carry out information integration, low interoperability of software, domination of static information visualization, and ineffectiveness of conventional management modes, this article believes that the future development of BIM may be further deepened in three aspects.

Firstly, to establish a unified platform through digital twin technology, to connect BIM, CMMS, ERP, IoT, and other system functions to the intermediate information platform, to achieve information integration, and to improve the efficiency of collaborative operations. Secondly, by integrating AI with BIM in depth, relying on the advantages of full-scale, whole process, and dynamic information of building models, to improve the accuracy and reduce the cost of training. Thirdly, when the building is demolished, the original BIM model and life cycle information related to material, building structure, vibration, daylighting and other aspects need to be kept to implement demolition optimization and material recycling and life cycle assessment.

In general, the information provided in this article can serve as a good guide for integration, decision support, and building information reuse O&M managers.

At the same time, this study has some limitations. First, since this study is based on the analysis and discussion of existing literature, there is currently a lack of practical cases in this paper, which makes it difficult to quantitatively evaluate the practical application effect of the methods proposed in the O&M operation of the building. Second, this paper is mainly oriented to the multiple development directions of a single aspect, which can only be understood so far and lacks in-depth discussion on the differences in application scenarios of different buildings. Moreover, information reuse after the passage of building life cycle still needs more frontier theoretical support and practical case support.

At present, there are great challenges for BIM in the O&M phase. For example, how to further integrate information of different information systems, where the duty boundary lies for data updating or maintaining after the platform is established, and how the permission and boundary for information sharing should be determined. These issues directly affect the sustainability and widespread application of BIM in building O&M. As BIM keeps developing in building O&M, it can be further combined with other advanced technologies, such as construction automation and edge computing, and applied to site patrol, responsive action, and intensive control. It is thus apparent that building O&M has great research interest and space for BIM, and both its application aspects and research value also need further discussion and study.

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